Basin Modeling in the SF Bay Area –
Annual Project Summary

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Investigations Undertaken

This study investigates seismic wave amplification in the Santa Clara Valley (SCV) and northern San Francisco Bay area using teleseismic waveforms and microtremor (microseismic noise) recorded by the Santa Clara Valley Seismic Experiment (SCVSE) and the Oakland San Francisco Urban Seismic Array (OSFUSA). We have built upon our previous results which showed that teleseismic P-waves are sensitive to the deep basin structure of the SCV, and have quantified the arrival time delays, primary phase amplification, and integrated squared velocity ground motion parameters, and have modeled these ground motion parameters at the SCVSE sites.

In the present study we have incorporated microtremor observations to investigate spectral amplification in the SCV. In addition, we have begun reducing the teleseismic wave observations from the OSFUSA to examine north bay area basin structure.

The major tasks of the present project outlined in the research proposal include:

1. Computation of horizontal to vertical spectral ratios (H/V ratios) of microtremors recorded by the Santa Clara Valley Seismic Experiment (SCVSE).
2. Collect and perform data processing for teleseisms recorded by the Oakland San Francisco Urban Seismic Array (OSFUSA).
3. Compute H/V spectral ratios for the San Juan Bautista earthquake and teleseisms recorded by the SCVSE.
4. Model the H/V spectral data using the propagator matrix method (e.g. Bodin et al., 1999), and methods of Nakamura et al. (1989), Uebayashi et al. (2003) and Yamanaka et al. (1993, 1994), and if required by 3d simulation.
5. Estimate teleseismic P-wave arrival delays and amplification, wave energy, and microtremor for the OSFUSA data set.

Results

We have completed tasks 1, 2, and 3, and are in the process of the modeling of H/V ratios (task 4). The H/V modeling and the investigation of OSFUSA teleseismic arrival delays and amplification are underway and will be completed in the remaining time for the project. We have determined empirical relations describing teleseismic arrival delay, amplification, and wave energy as a function of reported basin thickness for both the UCB (Stidham et al., 1999) and the USGS V2 (Brocher et al., 1994; Jachens et al., 1997) 3d velocity models. In addition, we have developed empirical relations between the microtremor H/V periods and basin thickness, and these are related to the teleseismic wave and local S-wave amplification in the basin. These results are reported in two papers which have been submitted to BSSA (e.g. Dolenc et al., 2003; and Dolenc and Dreger, 2003). The first paper documents our analysis of teleseismic parameters for the SCV, and the second documents the microtremor observations for the SCV, and relates the teleseismic and microtremor amplification to local-earthquake S-wave amplification. In the following some of the major results obtained to date are described.

Our previous project investigated ground motion parameters of teleseismic wavefields incident to the SCV. Figure 1 illustrates the strong correlation between arrival time delay, relative amplification, and relative energy of teleseismic waves recorded by the SCVSE with respect to basin depth from the USGS V2 3d seismic velocity model. The average arrival delays (Figure 1a) were determined by measuring P-wave arrivals using waveform cross-correlation, and then removing a plane-wave arrival function to highlight the residuals. The arrival delay residual varies between +- 0.25 seconds, and is seen to correlate linearly with basin depth from 0 to 4 km. The relative amplitude (Figure 1b) is the amplification of P-waves at basin sites with respect to P-wave amplitude at a site located outside the basin. P-wave amplification of as much as a factor of 1.7 is observed in the basins. The relative energy (Figure 1c) was determined by integrating the squared velocity time series over a 2-minute time window beginning at the P-wave arrival, and then normalizing by the wave energy obtained at the same non-basin site used to obtain the relative amplification in Figure 1b. The relative wave energy displays the strongest increase with respect to basin depth. This increase is a function of both the amplification of the primary P-wave as well as the level of P-coda over the 2-minute period. This work has been submitted for publication (Dolenc et al., 2003), and the above correlations agree with the results obtained by Fletcher et al. (2003). Encouraged by these results we began to investigate the microtremor characteristics in the SCV.

We have investigated the raw amplification of microtremor signals in the SCV and have found a strong spatial correlation with the deep basins. To further quantify this we utilized the H/V ratio technique in which the spectral ratio of horizontal and vertical microtremor is determined and modeled (e.g. Bodin et al., 1999). We investigated variations in amplitude of the H/V ratios and found no correlation, however a strong correlation with basin depth and the period of the maximum of the H/V ratio was found (Figure 2, and Figure 3). We are in the process of modeling these H/V ratio observations using a propagator matrix method (e.g. Bodin et al. 1999) using a code based on Kennett and Kerry (1979).

In addition to validating and obtaining data necessary to refine the 3d velocity structure of the SCV the objective of this research is to find relationships between basin parameters and strong ground motion amplification of local earthquakes. We have computed peak ground motion parameters and wave energy for two small earthquakes recorded by the SCVSE, namely the San Juan Bautista (08/12/1998, M_L=5.4) and the Gilroy (10/10/1998, M_L=4.0) events. Figure 4 shows vertical component integrated squared velocity, and peak ground velocity for the vertical and geometric mean of the horizontal components plotted as a function of basin depth. The data for each event was normalized by the average ground motion from the shallowest basin depth sites allowing the data from the two events to be plotted together.

There is a positive correlation in which the ground motion parameters are increasing functions of the basin depth. The correlation with basin depth appears to be strongest for the vertical component measures. Interestingly the correlation is also strongest for the Gilroy earthquake. This event has less of an influence from heterogeneity outside the basins as it is significantly closer to the SCV.

The dispersion of the local-earthquake amplification data is greater than that for both the teleseismic and microtremor data. This is likely due to the fact that the local-earthquake wavefields are complex and sensitive to crustal structure along the path outside the basins, and are likely more strongly influenced by seismic wave interactions along the basin edges. That is the teleseismic wavefields being more steeply incident are more sensitive to the basin-basement impedance contrast than the basin edges, and the microtremors are sensitive to basin resonnance. Nevertheless, the positive correlations of the local-earthquake amplification data indicates that we will be able to develop relationships between the teleseismic parameters, basin depth, and local-earthquake seismic wave amplification. Such a relationship and its uncertainty will be a product of this research. The derived relationship can possibly be used in the design of new attenuation relationships for strong ground motions, such as in the addition of basin depth terms. It can also be employed to further characterize SCV basin response by tying in observations from future SCV instrument deployments to the SCVSE sites used in this study.

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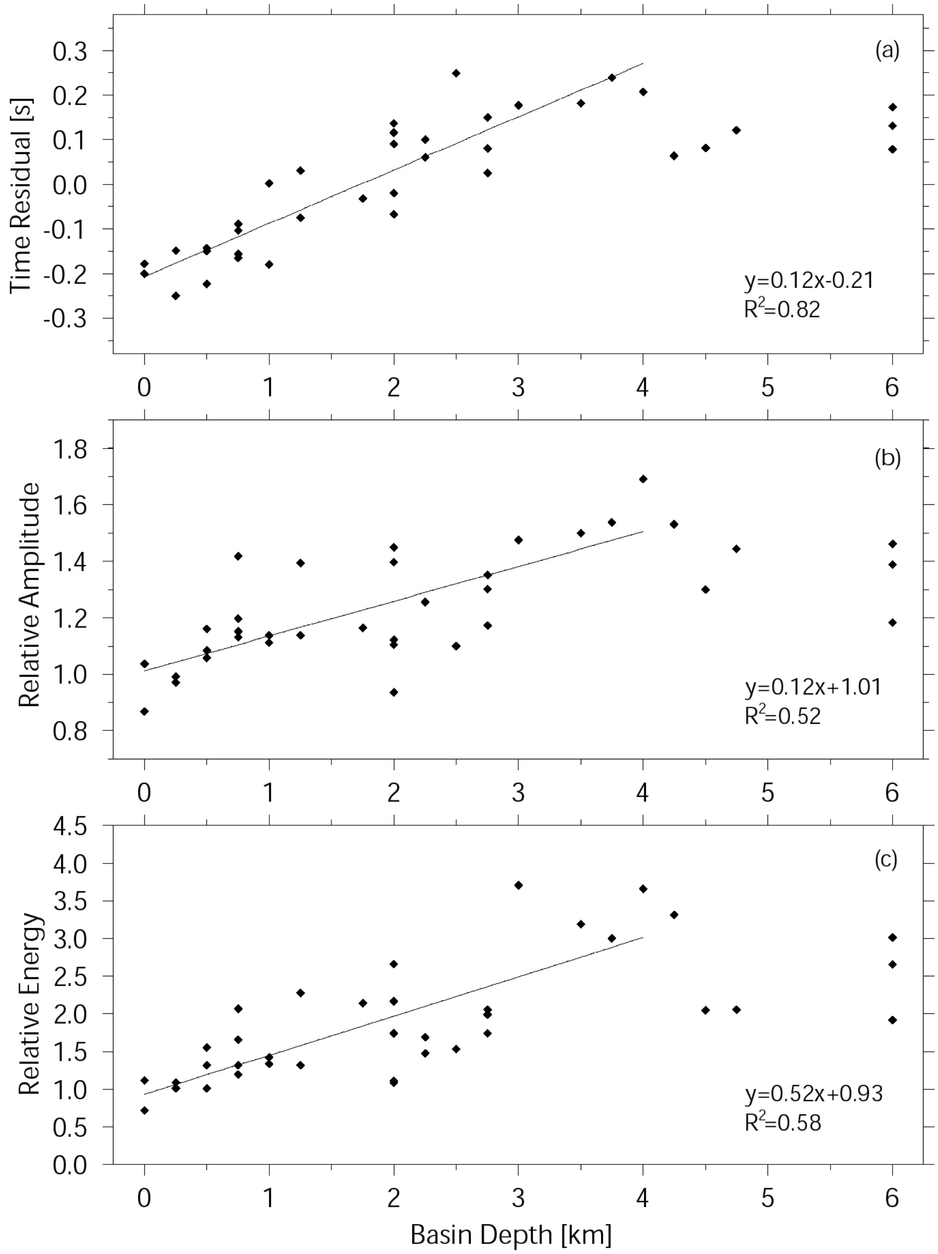

Figure 1. Correlation of telseismic arrival delays (a), relative amplitude (b), and relative wave energy (c) with basin depth from the USGS V2 3d seismic velocity model. Linear relations between each of the observables and basin depth are determined over the range from 0 to 4 km. Each of the observables appears to saturate for basin depths greater than 4 km suggesting that the actual maximum basin depth in the Santa Clara Valley is approximately 4 km.

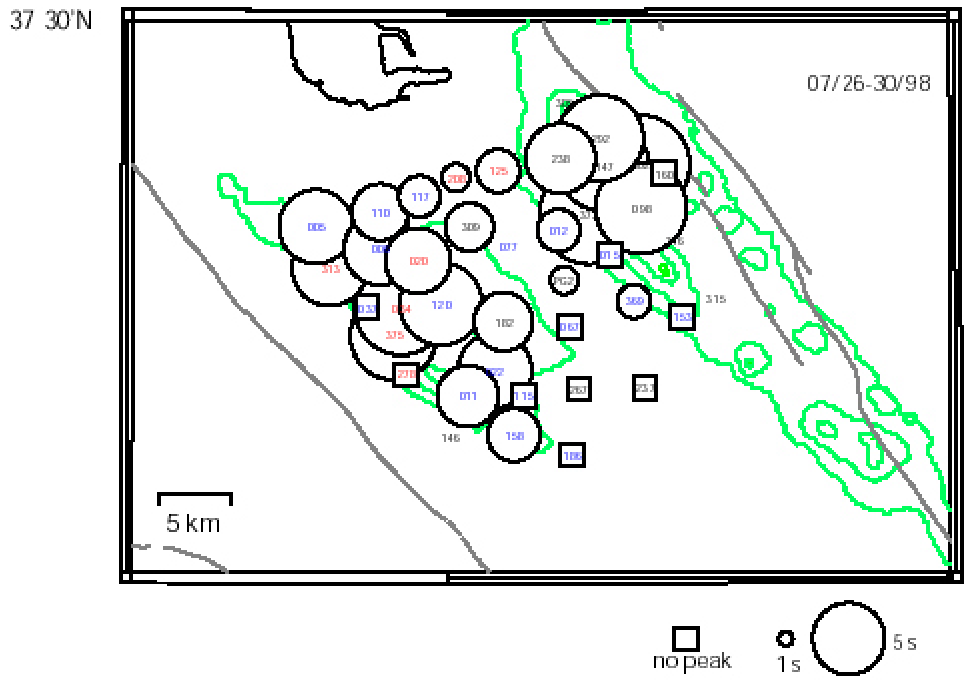

Figure 2. Mapview presentation of the period of the maximum H/V spectral ratio of microtremor recorded by the SCVSE. The green lines show 1 km contours of basin thickness in the USGS V2 3d velocity model. The dominant microtremor H/V period is found to correlate strongly with the deep basins. Note how the period shortens between the two deep basins. Sites illustrated as squares had no discernable peak and are generally located outside the basins or near the edges of basins.

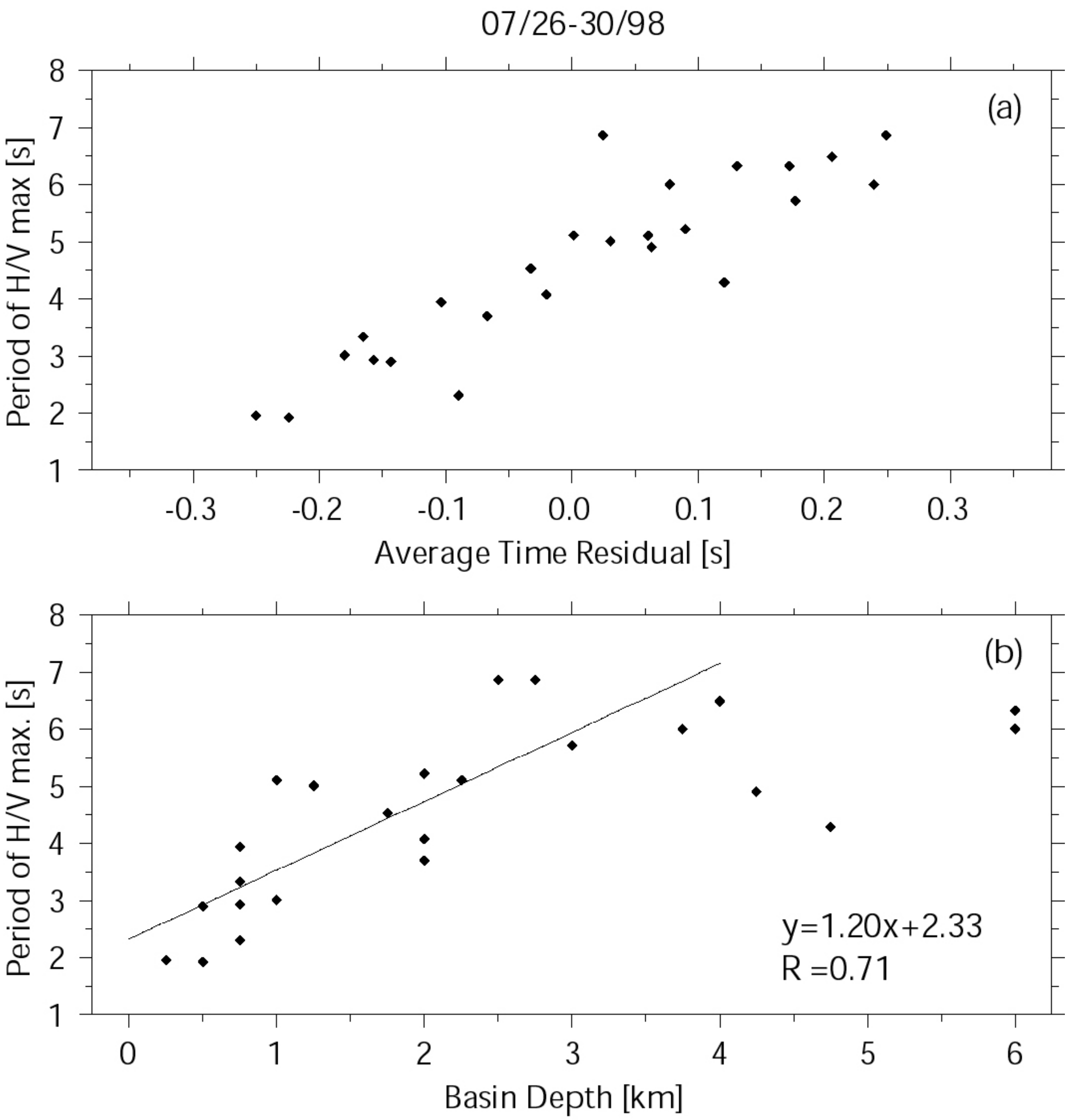

Figure 3. Correlation of microseism H/V period with average teleseismic arrival delays (a) and basin thickness (b) from the USGS V2 3d seismic velocity model. A line fit to the H/V vs. basin depth data over the range from 0 to 4 km depth is shown. The microseism H/V period is seen to saturate for basin depths greater than 4 km as was observed for the teleseismic event ground motion parameters (Figure 1).

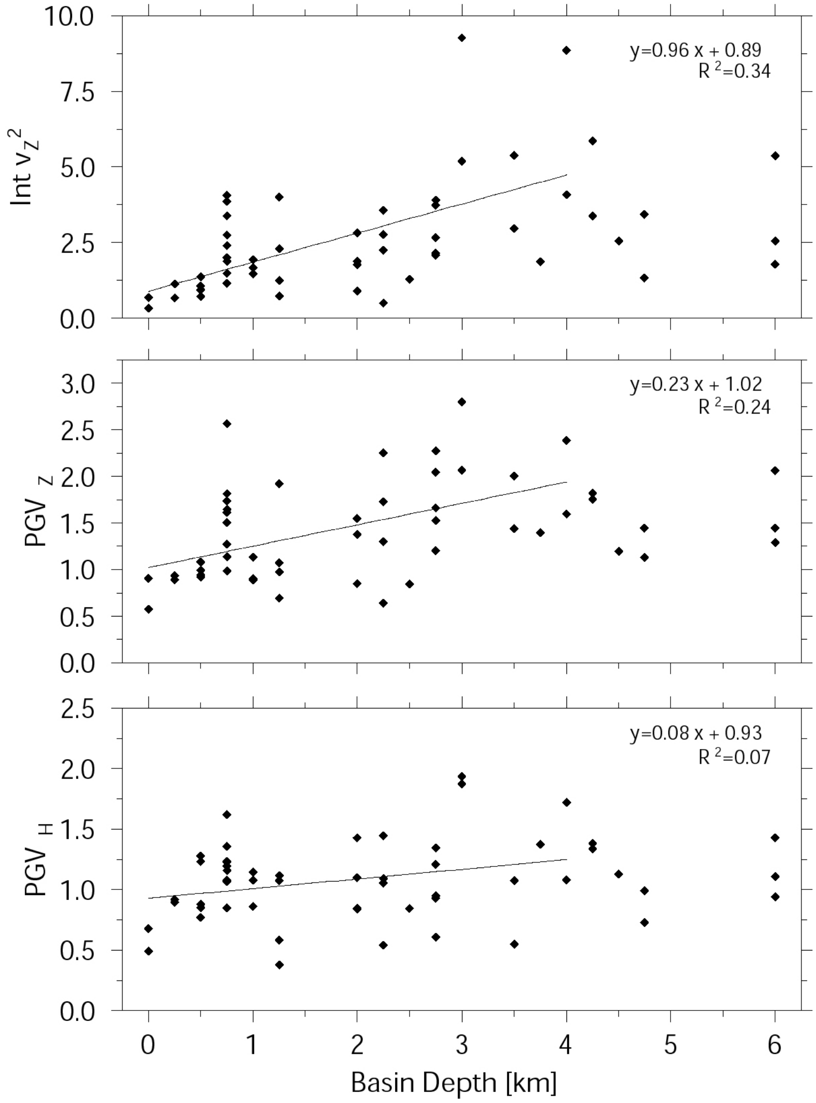

Figure 4. Local seismic wave amplification. Vertical component integrated squared velocity (e.g. energy) (a), vertical component peak ground velocity (b), and the geometric mean of the peak horizontal velocities (c) are compared to basin depth. Each ground motion parameter plotted is a relative measure with respect to a non-basin site of the SCVSE. Linear fits over the range of 0 to 4 km basin depth are provided. In each case the relative ground motion parameters are found to be an increasing functions of the basin thickness.

Non-technical Summary

This project investigates the amplification of seismic ground motions due to three-dimensional sedimentary basin structure in the Santa Clara Valley and northern San Francisco Bay area by modeling the amplification and spectral characteristics of background microtremor noise, and seismic wave characteristics of records from distant earthquakes. The objective of this work is to validate, refine, and calibrate existing three-dimensional basin structure in the San Francisco Bay area. Such calibrated seismic velocity models will be used to simulate strong ground motions for earthquake scenarios, which will facilitate assessment of future earthquake hazard.

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Data Availability Statement (with PI contact information)

Raw waveform data from the SCVSE and OSFUSA is available from the IRIS DMC. Measurements of teleseismic, microseismic, and local earthquake ground motion parameters may be obtained from the PI by sending email to dreger@seismo.berkeley.edu.